Romidepsin for Cutaneous T-cell Lymphoma

H. Miles Prince1,2 and Michael Dickinson1,2

Abstract

Cutaneous T-cell lymphomas (CTCL) are relatively rare lymphomas with an annual incidence of approximately 0.2 to 0.8/100,000 and comprise a variety of clinical entities; mycosis fungoides or its leukemic variant Sezary syndrome account for the majority of cases. Advanced-stage disease is typically treated with bexarotene (a retinoid), interferon, or conventional chemotherapeutic agents, but relapses are inevitable. Histone deacetylase inhibitors, which modify the epigenome, are an attractive addition to the armamentarium. On the basis of 2 large phase II studies, the U.S. Food and Drug Administration approved intravenous romidepsin for patients with relapsed and/or refractory CTCL. Romidepsin provides a subset of patients with an opportunity for prolonged clinical responses with a tolerable side effect profile. Clin Cancer Res; 18(13); 3509–15. ©2012 AACR.

The Histone Deacetylase Inhibitors

The histone deacetylase (HDAC) inhibitors target not only the epigenome via histone modification, but also numerous nucleic and cytoplasmic nonhistone proteins. They are powerful and selective inducers of cancer cell apoptosis and modifiers of the tumor microenvironment, as reviewed recently by Dickinson and colleagues (1) and depicted in Fig. 1. HDACs are one target for HDAC inhibitors and can be grouped according to their structure and homology to yeast enzymes and share a common mechanism of action in binding a zinc ion critical to HDAC function.

The simplest method of grouping HDAC inhibitors is based on specificity. Class I–specific HDAC inhibitors include benzamide derivatives (entinostat, mocetinostat) and cyclic tetrapeptides. Romidepsin, isolated from Chromobacterium violaceum (previously called depsipeptide, FK228, FR901228) is one such cyclic peptide (1). The pan-HDAC inhibitors include the hydroxamic acid derivatives [trichostatin A, vorinostat (suberoylanilide hydroxamic acid), and panobinostat (LBH589)]. They were thought to inhibit all of the zinc-dependent HDACs; however, recent data suggest a relatively reduced effect of the hydroxamates to inhibit class IIa enzymes (HDACs 4, 5, 7, and 9; ref. 2). A key difference between the pan-HDAC inhibitors and the class I–specific HDAC inhibitors is thought to be the inhibition of cytoplasmic HDAC6. It is important to note here that, currently, very little suggests that this potential mechanistic difference between the pan-HDAC inhibitors and the isotype-selective HDAC inhibitors, such as romidepsin, affects the response rates [in cutaneous T-cell lymphoma (CTCL), at least]. Response rates to the pan-HDAC inhibitor vorinostat in CTCL are similar to those of romidepsin; however, there may be a difference in toxicity profiles.

Preliminary Studies of Romidepsin

Romidepsin induces apoptosis in many human tumor cell lines and in various xenograft models (3–5). The most comprehensive preclinical studies of romidepsin in a CTCL model have been done by Piekarz and colleagues (6). These investigators used the human T-cell lymphoma cell line HUT78 to test for sensitivity and molecular response. Administration of romidepsin resulted in histone acetylation, induction of p21 expression, expression of the interleukin-2 receptor, apoptosis without cell-cycle arrest, and induction of the multidrug resistance pump P-glycoprotein (Pgp/ABC1B). Pgp was overexpressed in romidepsin-resistant cells, raising the possibility that romidepsin directly induces a mechanism for its own resistance (6).

Romidepsin Metabolism and Pharmacokinetics

Romidepsin is extensively metabolized in vivo, primarily by cytochromes P450 (CYP) 3A4 and to a lesser extent by CYP3A5. In rats, 66% of the dose is excreted into the bile, thought to be via Pgp/ABC1B. Romidepsin is also likely to be a substrate of the organic anion transporter OATP1B3, an influx transporter encoded by SLCO1B3, as other cyclic peptides have been found to interact with the same transporter.

Romidepsin is currently only available as an i.v. formulation. In humans, following a 4-hour infusion, its half-life is approximately 3.5 hours, more than 90% protein bound, metabolized predominantly by CYP3A4, and 66% excreted in bile. The disposition of romidepsin has been shown to
follow a polyexponential decline with a linear elimination and has been described by a 2-compartment pharmacokinetic (PK) model. No apparent nonlinearity has been reported for romidepsin disposition within the range of 1 to 24.9 mg/m² (7, 8) The PK of romidepsin does not seem to be affected by repeated dosing. The most extensive clinical PK analysis was done recently by Woo and colleagues (9), in which 98 patients were enrolled in a phase II National Cancer Institute (NCI) study (described below). Patients were tested after they received 14 mg/m² or 18 mg/m² of romidepsin as a 4-hour infusion on day 1 during their first treatment cycle. Population modeling was done using a nonlinear mixed effects modeling approach to explore the effects of polymorphic variations in CYP3A4, CYP3A5, SLC01B3, and PGP/ABCB1, all of which encode genes thought to be involved in romidepsin disposition. There was moderate interpatient PK variability in clearance (37%), and no statistically significant association was found between romidepsin PK and patient-specific covariates, including the polymorphic variants of the cytochrome p450 system tested (9). The pharmacokinetic pathways involved here will be critical for future drug combination studies, in which clinically relevant drug interactions may occur.

Early Clinical Studies of Romidepsin

There have been multiple phase I trials with romidepsin in patients with refractory solid tumors (7, 8), chronic leukemia, myeloma (10), acute myeloid leukemia (11), and T-cell lymphoma. The maximum-tolerated dose was established at 17 to 18 mg/m² infused over 4 hours on day 1 and day 5 of a 21-day cycle and 13.3 mg on days 1, 8, and 15 of a 28-day cycle. In general, romidepsin was well tolerated, and dose-limiting toxicities were constitutional symptoms and thrombocytopenia (7, 8, 10, 11). A phase I trial at the NCI showed significant activity in patients with CTCL, with 3 partial responses (PR) observed and one complete response (CR) in a patient with peripheral T-cell lymphoma (PTCL); this study ultimately led to the expanded phase II studies (12).

Trials of Romidepsin in Cutaneous T-Cell Lymphoma

Romidepsin is an effective agent for the treatment of CTCL. Data are available from 2 large phase II studies, an international study based at the NCI in the United States (13), and the other, global (14). The treatment schedule was identical across both studies, 14 mg/m² i.v., days 1, 8, and
15, of a 28-day cycle. The NCI study by Piekarz and colleagues (13) had a standard Simon 2-stage design, with the initial cohort of patients having received not more than 2 systemic therapies. The 44 patients recruited in the second stage of the study were more heavily treated, and in the overall study, patients had received a median of 4 prior regimens. The severity of disease was similar to that shown in the other studies of HDAC inhibitors in CTCL (Tables 1 and 2). The overall response rate of 34% included 4 CRs. Of the 20 patients that experienced a PR, 13 had involvement of blood, nodes, or viscera. The response duration was a clinically meaningful 13.7 months for the 24 patients achieving a CR or PR and 4 months for those with stable disease. Responses occurred at a median of 8 weeks. Symptomatic responses, such as improvement in pruritis, were not reported. In a separate analysis of patients in this trial, Bates and colleagues evaluated molecular endpoints gathered from a 61-patient subset enrolled (including some PTCL patients included in this study). The biomarker endpoints included histone H3 acetylation and *MDR1/ABCB1* gene expression in peripheral blood mononuclear cells (PBMC; refs. 15, 16); *ABCB1* gene expression in tumor biopsy samples; and blood fetal hemoglobin levels, all of which were increased following romidepsin treatment. With respect to histone acetylation in PBMCs at 24 hours, there was a weak-to-moderate correlation with PK parameters of Cmax and AUClast, inversely associated with drug clearance. Histone acetylation in PBMCs at 24 hours was associated with response (*P* = 0.026), as was the increase in fetal hemoglobin (*P* = 0.014). The association of response with histone

<table>
<thead>
<tr>
<th>Study characteristics</th>
<th>Vorinostat</th>
<th>Romidepsin</th>
<th>Panobinostat</th>
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<tbody>
<tr>
<td>Reference</td>
<td>Olsen et al. (27)</td>
<td>Duvic et al. (22)</td>
<td>Whittaker et al. (14)</td>
</tr>
<tr>
<td>Patients, N</td>
<td>74</td>
<td>33</td>
<td>96</td>
</tr>
<tr>
<td>Age: median (range)</td>
<td>60 (39–83)</td>
<td>67 (26–82)</td>
<td>57 (mean)</td>
</tr>
<tr>
<td>CTCL stage, n (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IA</td>
<td>0</td>
<td>1 (3)</td>
<td>0</td>
</tr>
<tr>
<td>IB</td>
<td>11 (14.9)</td>
<td>3 (9)</td>
<td>15 (16)</td>
</tr>
<tr>
<td>IIA</td>
<td>2 (2.7)</td>
<td>1 (3)</td>
<td>13 (14)</td>
</tr>
<tr>
<td>IIB</td>
<td>19 (25.7)</td>
<td>5 (15)</td>
<td>21 (22)</td>
</tr>
<tr>
<td>III</td>
<td>20 (27)</td>
<td>5 (15)</td>
<td>23 (24)</td>
</tr>
<tr>
<td>IVa</td>
<td>18 (24.3)</td>
<td>10 (30)</td>
<td>25 (25)</td>
</tr>
<tr>
<td>IVB</td>
<td>4 (5.4)</td>
<td>8 (24)</td>
<td>0</td>
</tr>
<tr>
<td>Number of prior therapies, n (range)</td>
<td>3 (1–12)</td>
<td>5 (1–15)</td>
<td>4 (1–11)</td>
</tr>
<tr>
<td>Time from original diagnosis in years (range)</td>
<td>2.9 (0.7–27.3)</td>
<td>3.3 (0.2–27.2)</td>
<td>3 (1–26)</td>
</tr>
<tr>
<td>Sézary blood involvement</td>
<td>30 (40.5)</td>
<td>11 (33)</td>
<td>37 (39)</td>
</tr>
<tr>
<td>Prior oral bexarotene</td>
<td>71 (95.9)</td>
<td>22 (67)</td>
<td>32 (33)</td>
</tr>
<tr>
<td>Prior chemotherapy</td>
<td>45 (60.8)</td>
<td>29 (88)</td>
<td>74 (77)</td>
</tr>
<tr>
<td>Percent overall response</td>
<td>29.7</td>
<td>24.2</td>
<td>34</td>
</tr>
<tr>
<td>Complete responses, n (%)</td>
<td>1 (1.4)</td>
<td>0</td>
<td>6 (6)</td>
</tr>
<tr>
<td>Median weeks to response (range)</td>
<td>7.9 (4–24.4)</td>
<td>11.9 (3.6–21.9)</td>
<td>8 (3.6–19.2)</td>
</tr>
<tr>
<td>Median duration of response, months (range)</td>
<td>NS but estimated ≥ 6.16 (1–14.7)</td>
<td>15.1 (9.4–19.6)</td>
<td>15 (0–19.8)</td>
</tr>
<tr>
<td>TTP, mo</td>
<td>4.9 (≥9.8 for stage IIB or greater)</td>
<td>2.82</td>
<td>8 (0–21.7)</td>
</tr>
<tr>
<td>Duration of treatment, median months (range)</td>
<td>8 (4–67)</td>
<td>8 (1–67)</td>
<td>NS</td>
</tr>
</tbody>
</table>

Abbreviations: NS, not stated; PFS, progression-free survival; SD, stable disease; TTP, time to progression.
acetylation in PBMCs at 24 hours is consistent with a hypothesis that potent HDAC inhibitors are needed for a critical threshold of drug exposure and durable activity (16).

The findings of the pivotal 33-center phase II study of romidepsin by Whittaker and colleagues (14) were consistent with those of the NCI study. A total of 96 patients were treated. Response criteria were more rigorous in the skin, using the modified severity weighted assessment (mSWAT) tool (see below), and were more inclusive for lymph nodes, using the Response Evaluation Criteria in Solid Tumors (RECIST) criteria. The authors had an umbrella response score that incorporated all domains of disease (skin, blood, and nodes). Nevertheless, they were able to show an identical response rate of 34%, time to response of 8 weeks, and median response duration of 15 (0–19.8) months. This study included assessment of pruritis by a visual scale, as used in the vorinostat studies (below), and ≥30 mm reduction was seen in 43% of the 65 patients with pruritis, including those without objective disease responses.

### Safety

As a class of agents, the HDAC inhibitors share a similar toxicity profile; however, there may be variation by HDAC

### Table 2. Methods of response assessment in romidepsin studies

<table>
<thead>
<tr>
<th>Reference</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Olsen et al. (27)</td>
<td>Skin: mSWAT PR, 50% reduction in mSWAT; CR, 100% clearing of skin disease; PD, 25% worsening of mSWAT from baseline or ≥50% increase in SPD of nodal disease; date of relapse, mSWAT score from nadir to ≥50% difference between the baseline and the nadir; confirmation of CR/PR, ≥4 weeks; confirmation of SD, not defined; pruritis, VAS with 30-mm reduction for at least 4 weeks considered significant, with no increase in use of antipruritis medications; separate reporting of nodal response, not reported in overall response results: ≥50% reduction in nodal disease or ≥25% reduction in blood tumor burden.</td>
</tr>
<tr>
<td>Duvic et al. (22)</td>
<td>PGA; PR, ≥50% improvement in either BSA or skin score with reduction of lymph nodes or blood when involved. PD, ≥25% increase in the number or area of clinically abnormal nodes, or percentage of BSA or new visceral disease or increase in circulating Sézary cells. Pruritis, 30% reduction of VAS for 4 weeks. Confirmation of CR/PR, 4 weeks. Confirmation of SD, 8 weeks. Confirmation of PD, 4 weeks.</td>
</tr>
<tr>
<td>Whittaker et al. (14)</td>
<td>LN, RECIST. Skin, Composite of SWAT score and erythroderma scores. PR, 50% improvement in the sum of Cheson, SWAT, and erythroderma scores but with ≥30% improvement in skin and no worsening at any site. PD, new cutaneous or noncutaneous tumor or ≥25% improvement in the sum of the 3 assessments or ≥15% worsening of skin. CR, response at all sites. Pruritis, VAS with 30-mm reduction for at least 2 cycles considered significant.</td>
</tr>
<tr>
<td>Plekarz et al. (13)</td>
<td>Skin or viscera, RECIST. LN, IWG/Cheson. Erythroderma, present or absent. Flow response, present or absent. PR, either a response in the skin or lymph nodes. CR, response in all sites of disease.</td>
</tr>
<tr>
<td>Duvic et al. (28)</td>
<td>Skin, mSWAT, PGA. Lymph nodes: Confirmatory CTs were done to exclude disease progression in the nodes at the time of response in the skin. PD, ≥25% increase in mSWAT compared with nadir. Confirmation of progression not required.</td>
</tr>
</tbody>
</table>

NOTE: Response assessment methods varied considerably across studies. Abbreviations: BSA, body surface area; CT, computer-assisted tomography; IWG, International Working Group; LN, lymph node; PD, progressive disease; PGA, Physician’s Global Assessment of Clinical Condition; SD, stable disease; SPD, sum of perpendicular diameters; VAS, visual analog scale.
inhibitor specificity. Those familiar with the treatment of advanced-stage CTCL with systemic chemotherapy will immediately notice the apparently low rates of grade 3 and 4 neutropenia, sepsis, or febrile neutropenia associated with the use of HDAC inhibitors. This ability to induce systemic responses without the need for aggressive prophylaxis against infection or for frequent hospitalization is key to the attractiveness of this biologic agent, when considered against chemotherapy.

Fatigue and asthenia are experienced by many patients, as are disorders of the gastrointestinal system and of taste. Nausea is frequent but generally easily treated with standard antiemetic agents. Thrombocytopenia occurred in 11% to 34% and was severe (grade 3 and 4) in up to 6% of patients. The thrombocytopenia of HDAC inhibitors is rapidly reversible upon withdrawal of the drug, and does not worsen with prolonged romidepsin exposure (17). Although megakaryocyte numbers increase in response to HDAC inhibitors, platelet budding is defective (18).

As a consequence of rare episodes of cardiac dysrhythmia in phase 1 studies, electrocardiography assessments were systematically done in phase II studies. T-wave flattening was seen in 71% of patients in the NCI romidepsin study and ST segment depression in 9%. Clinically significant QTc prolongation was reported in 2 patients on the global romidepsin study, which also reported an average prolongation of the QTc interval of 4.6 ms (13). A more detailed study of the initial 42 patients in the NCI study, which included Holter monitoring in 9 patients, showed that the changes in QTc were not associated with elevated cardiac troponin or to changes in left ventricular ejection fraction (19). Other HDAC inhibitors, such as panobinostat and vorinostat, also have reports of prolongation of the QTc. QTc prolongation may well be dose and schedule dependent. It is interesting that in a carefully controlled study of vorinostat, in which supratherapeutic doses were administered, no alteration in QTc was observed (20). Nevertheless, as a consequence of the clinical reports, drugs that prolong the QTc should be avoided. Replacement of potassium and magnesium within normal limits prior to therapy is required prior to the romidepsin infusion. Romidepsin competes with estrogen for its receptor, so the oral contraceptive pill must be assumed to be an ineffective contraceptive when used alone.

**Romidepsin in Cutaneous T-cell Lymphoma in Comparison with Other HDAC Inhibitors**

In general, HDAC inhibitor therapy induces objective responses in CTCL in the order of 25% to 30% across studies, and each agent is similarly well tolerated (Tables 1 and 2). The responses take a median of 8 weeks and up to 2 years to occur and seem to last somewhere between 6 and 15 months in responding patients. However, if future clinical practice reflects the experience observed in clinical trials, patients will only receive 3 cycles of treatment prior to cessation because of disease progression or drug intolerance. Vorinostat was the first HDAC inhibitor approved by the U.S. Food and Drug Administration (FDA), in 2006, for patients with CTCL who had failed 2 prior systemic therapies. Unfortunately, direct comparisons of clinical response between the HDAC inhibitors are difficult to make, no randomized studies compare the various HDAC inhibitors in CTCL, and the recently published consensus criteria did not exist at the time of design of the various studies discussed here. Nonetheless, romidepsin seems to induce a comparable rate and durability of response to that of vorinostat (Tables 1 and 2).

Like vorinostat, panobinostat is also available in oral formulation. Panobinostat seems to have both a lower response rate and shorter duration of response and, to date, has not been registered by the FDA. However, these differences may be attributable to the very stringent response and progression criteria used in the panobinostat study.

**Mechanism of Action in T-cell Lymphoma: Biomarkers and Hypotheses**

The accessibility of the skin for biopsy means that CTCL provides an opportunity for the study of the effects of HDAC inhibitors on tumor cells in vivo, giving us more insights than other types of malignancy allow. In CTCL, STAT3 phosphorylation is increased in a cytokine-independent manner, possibly as a consequence of defective T-cell receptor signaling (21). Studies with the other HDAC inhibitors in CTCL have given us further insight into possible mechanisms of action. For vorinostat, cellular localization of phospho-STAT3 seems to be predictive of response (22, 23). Duvic and colleagues also showed that thrombospondin 1, an inhibitor of angiogenesis, is upregulated after exposure to vorinostat, supporting the hypothesis that antiangiogenic effects are important to HDAC inhibitor activity in CTCL (22). Following a genome-wide loss-of-function screen, Khan and colleagues went on to show that patients whose tumors had higher levels of expression of HR23B by immunohistochemistry at baseline were more likely to have responsive disease (24). HR23B has a ubiquitin-like domain and shuttles proteins to the proteasome for degradation. The finding supported the concept that disruption of the proteasome is important in CTCL, and the authors suggested that it could be a useful biomarker. Further studies elucidating the precise mechanism and whether romidepsin exerts a similar effect are required. With respect to panobinostat, Ellis and colleagues provided further support for the antiangiogenesis hypothesis (25). They did serial gene-expression profiling on samples from 10 patients with CTCL treated with panobinostat and showed consistent changes in expression in a set of 23 genes, including downregulation of expression of various transcription factor, cell-cycle, immune regulatory, and angiogenic genes.

**Placing Romidepsin in Overall Cutaneous T-cell Lymphoma Therapy: Future Directions**

There are no standard algorithms for the management of CTCL; suffice it to say that in advanced-stage disease, chemotherapy is deferred for as long as possible, with a
preference to choose a biologic agent as the first systemic therapy (26). Thus, most treating physicians would choose bevacizumab as the first-line agent because of its good toxicity profile and its availability as an oral agent. For most clinicians, the next line of therapy will likely be a choice of interferon, an HDAC inhibitor, or single-agent therapy, such as oral methotrexate. Pralatrexate is approved for PTCL and has activity in CTCL. The fusion protein denileukin diftitox is also effective in this group but requires i.v. infusions. Currently, on the basis of the evidence and label restrictions, we reserve HDAC inhibitors for second- or subsequent-line therapy of CTCL (26). The possibility of protracted responses makes HDAC inhibitors an attractive option for patients with advanced and symptomatic CTCL. HDAC inhibitors are also effective in earlier stages of disease and are generally well tolerated. Of note, they have a moderately rapid onset of action and if effective, improvements in skin disease are usually observed within a few weeks of the commencement of therapy.

Once the decision to use an HDAC inhibitor is made, the clinician needs to choose between vorinostat or romidepsin. One potential advantage of vorinostat is its oral availability. The incidence of thrombocytopenia is generally lower than that of romidepsin, but this may, in part, be due to a dose or potency. In our experience, alterations in renal function seem to be more common with vorinostat.

Romidepsin needs to be administered weekly (3 of every 4 weeks) over a 4-hour infusion, which may make it impractical for some patients. Fatigue and thrombocytopenia are the most common adverse effects, but they are relatively easy to manage. Although there are no direct comparative trials, the depth and length of responses with romidepsin seem superior.

For the future, combinations with other agents to improve responses and outcomes present an attractive concept, with a strong rationale existing for combinations with proteasome inhibitors, immunomodulatory agents such as lenalidomide and denileukin diftitox, and the DNA demethylating agents.

Disclosure of Potential Conflicts of Interest
H.M. Prince received commercial research grants from and is a consultant to Celgene, Merck, and Novartis and received honoraria from Celgene and Novartis. No potential conflicts of interest were disclosed by the other author.

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Conception and design: H.M. Prince, M. Dickinson
Development of methodology: H.M. Prince
Writing, review, and/or revision of the manuscript: H.M. Prince, M. Dickinson
Administrative, technical, or material support: M. Dickinson

Received January 24, 2012; revised March 14, 2012; accepted March 21, 2012; published OnlineFirst April 24, 2012.

References
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